Control System Design for Teleopration of Manipulators

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Extended Abstract

1. Introduction

Two typical control problems of manipulators are trajectory tracking motion in Cartesian space and the constrained motion on contacting surface of the environment during task performing. Several control methods of manipulators have been proposed and implemented to follow a desired path in three-dimensional space. However, these methods are not directly applicable when the manipulator end-effectors are required to make contact with the environment. Practical examples of such tasks are grinding, scribing and assembly related tasks in production factories, and opening doors, lifting bodies in rescue missions, and so on. In these applications, contact forces between the manipulator end-effector and the environment are generated. Those forces are frequently unpredictable and most likely indicate nonlinearities. Phase transition from free motion to such a constrained motion is a difficult control problem and a typical example of hybrid systems.

Resolved motion force control can be applied to the problem of tracking a desired trajectory with the desired forces maintaining, and impedance control is also applicable to a constrained motion. However, those methods are sometime too sensitive to changing factors of the contact; moreover, jump or chattering phenomena may occur during phase transition between free motion and the constrained motion if a simple switching strategy is taken for the phase transition. Our approach to cope with this problem is based on the following three ideas. First, remote operation by human with a teleoperator is a promising and practical solution under unpredictable changing environment factors. Second, a switching free control can be achieved for phase transition from free motion to the constrained motion. Third, human operator can learn to obtain a skilled motion for completing a given task if mental loads to the human operator are kept at a pleasant level.

2. Teleoperator for manipulation using functional electric stimulation

We have developed a new teleoperator to investigate the effectiveness of our ideas. The master and slave subsystems are shown in Fig.1. There are remarkable features in the teleoperator. First, there is no mechanical part in the master subsystem. Three small electrodes and two position/orientation sensors are attached on skin of upper limb. The upper limb works by itself as the master arm. Second, force reflection from the slave to the master is achieved by functional electric stimulation through the surface electrodes. Third, the structure of slave manipulator is kinematically similar to the master arm. This makes it easy for the operator to command the slave.

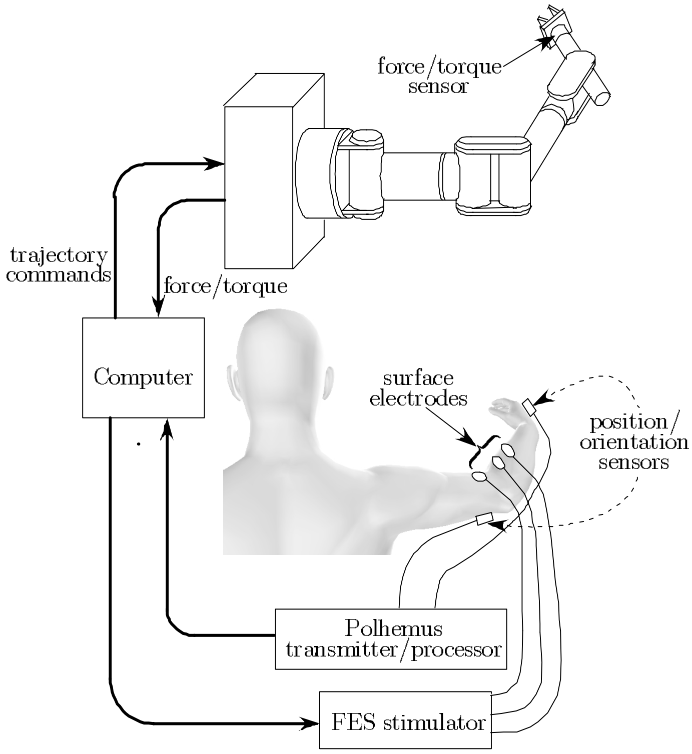

Fig.1 Master and slave subsystems

The block diagram of system is shown in Fig.2. Two magnetic Polhemus sensors on the operator arm measure the position and orientation in the master coordinate frame. The master arm can be modeled by a seven degree-of-freedom rigid link mechanism. So, we can calculate in real time the corresponding angles of the arm joints from the measurements, and then the calculated angles are sent as position commands to robot controller of the slave. The force sensor which is placed at the wrist of the slave manipulator measures the generated force and moments. Those are converted to the corresponding torques of the joints, which are reflected to the master for increasing the sense of telepresence of the operator. The reflection is conducted by stimulating the corresponding muscles. The operator feels the artificially generated forces as a reaction force with visual information in virtual world. In comparison with conventional joysticks or exoskeletal devices, operator with this new master subsystem manipulates more freely the slave because there is no physical constraint on his arm and hand.

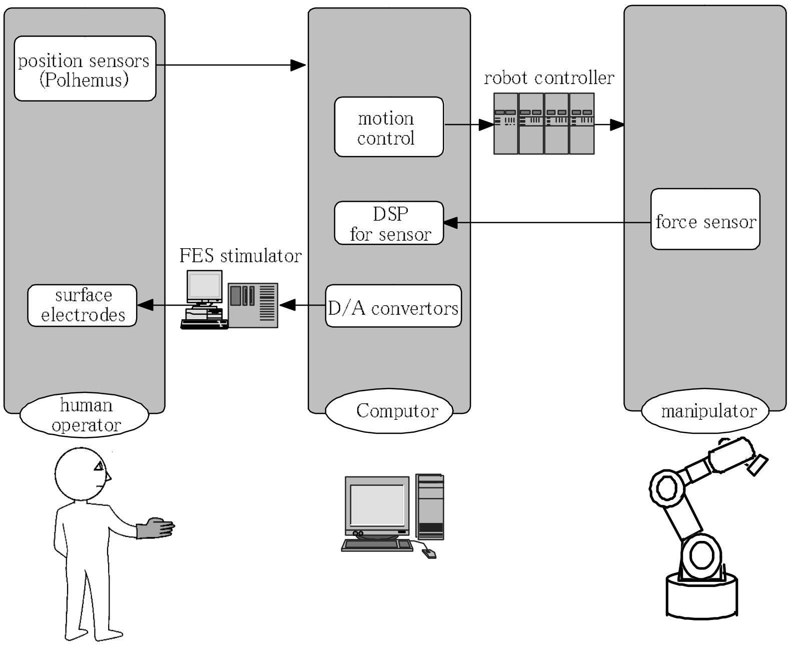

Fig.2 Block diagram

3. Control system design for teleoperator

A noted and difficult control problem of teleoperation is contact transition control with nonzero impact velocity or avoiding jump or instability phenomena due to switching the control law. We can solve the problem by increasing damping of the slave dynamics during a time interval including the impact instance. However, the increase of damping to the master dynamics gives a larger load to the operator. So, we have to pay our attentions in controller design not only on the slave dynamics also on the master dynamics for an easier maneuvering.

On the other hand, it is desirable to communicate precisely contact force information from the slave to master, and also for the slave to track exactly path command from the master, so as to couple the operator to the environment and increase the sense of telepresence. Since teleoprators are controlled bilaterally, we understand that those are acting as a hybrid control system, where the human operators determine the switching between position control and force control.

With the understandings in the above, we have tried to design the controller for our new teleoperator. It is not necessary to take the master dynamics into consideration because there is no artificial system which has an effect on the operator's dynamics of the master. The design objectives of control are as follows. First one is to compensate the delay which comes from the calculation of coordinate transformation and the processing of sensors information. This makes the stability margin become larger in the loop which consists of the teleoperator and human operator dynamics. Second objective is to achieve a smooth transition from free motion to constrained motion. This is effective to prevent chattering due to switching control law.

We have translated these design objectives into a set of frequency weightings of the generalized plants for optimal design of the controllers. The designed controllers are corresponding to given conditions of contacting or the free motion. Those controllers are scheduled and plugged in free parameters of the stabilizing central controller. The FIR realization is used for the subcontroller, which makes it possible to achieve a smooth switching between free motion and constrained motion.

4. Concluding remarks

We have developed a new teleoperator with FES force reflection so as to solve control problems of teleoperation. The controller is designed to achieve a smooth phase transition and a better sense of telepresence for the operator. It is shown in experimental results that the developed teleoperator with the designed controller is more effective to cope with phase transition problem and to increase sense of telepresence in comparison with conventional teleoperation systems.